Toward an International Lunar Polar Volatiles Strategy

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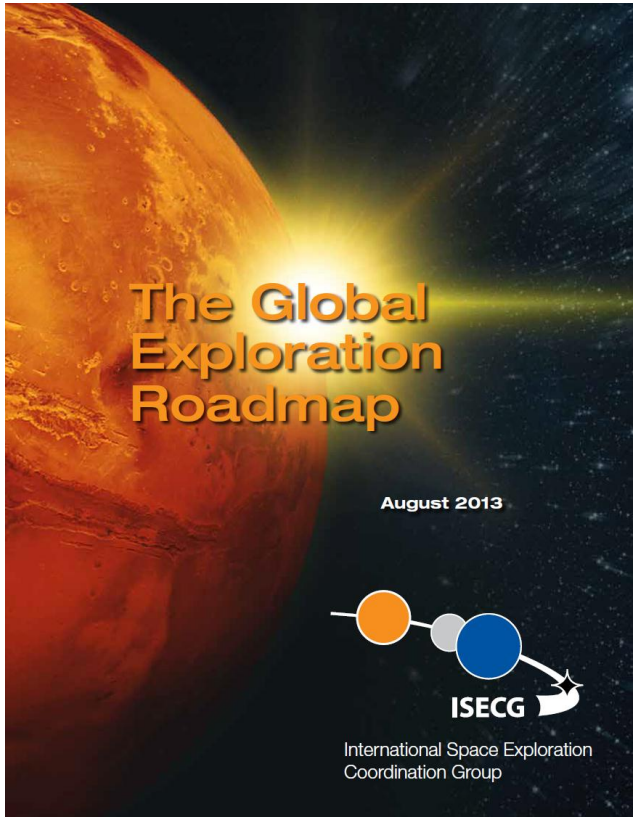
What is ISECG?

- **The International Space Exploration Coordination Group (ISECG)**
  - 14 national space agencies
  - Voluntary, non-binding international coordination forum and mechanism
  - Goal of strengthening both individual exploration programs as well as the collective efforts, working together to advance a long-range human space exploration strategy



- **Global Exploration Roadmap (GER)**
  - Highlights efforts preparing for human and robotic exploration beyond low-Earth orbit (LEO)
  - Creates a framework for interagency discussions
    - Common goals and objectives
    - Long-range human exploration strategy
    - Coordination of exploration preparatory activities

- **http://www.globalspaceexploration.org**

Global Exploration Roadmap 2014

ISECG

2020 2030

Low-Earth Orbit

International Space Station

Commercial or Government-Owned Platforms

Robotic Mission
Human Mission
Cargo Mission

Beyond Low-Earth Orbit

Test Missions

Rosetta
Hayabusa-2 (Sample Return)
OSIRIS-REx (Sample Return)
Asteroid Redirection
Apophis
Explore Near Earth Asteroid
Near-Earth Objects

Extended Duration Crew Missions
Staging Post for Crew to Lunar Surface
Lunar Vicinity
Potential Commercial Opportunities

LADEE
Luna 25
Chandrayaan-2
Luna 26
Luna 27
RESOLVE
SELENE-2
Luna 28/29 (Sample Return)
SELENE-3
Human-Assisted Sample Return
Humans to Lunar Surface
Moon
Potential Commercial Opportunities

Human-Assisted Sample Return
MAVEN
ISRO Mars Orbiter Mission
ExoMars 2016
InSight
ExoMars 2018
Mars 2020
JAXA Mars Precursor
Mars Sample Return Mission Opportunities
Human Scale EDL Test Mission Opportunities
Sustainable Human Missions to the Mars System
Mars

Multi-Destination Transportation Capabilities
(Planned and Conceptual)

Orion & SLS
Russian Piloted System
Advanced Electric Propulsion
Evolvable Deep Space Habitat
Orion & SLS (Upgrade)
Initial Cargo Delivery
Small Cargo Lander
Human Surface Mobility
Crewed Lunar Lander
Orion & SLS (Upgrade)

Icon indicates first use opportunity.
Commercial/Institutional launchers not shown.

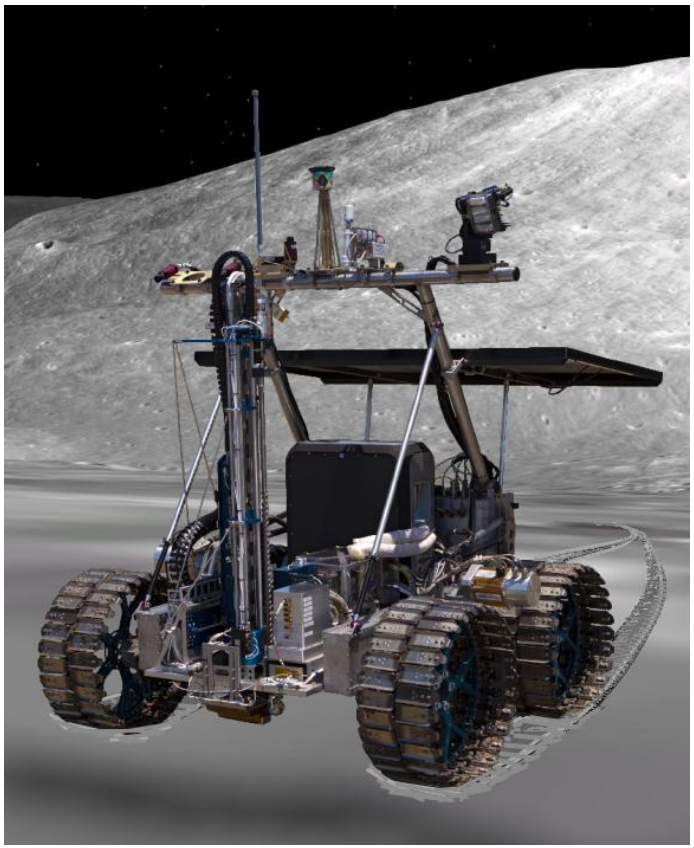
Why Lunar Polar Volatiles?

- **Sustainable, affordable human presence beyond LEO is a long-term goal of the GER**

- **Maintaining that presence may benefit significantly from use of local resources**
  - Limit cost and complexity of bringing all needed supplies from Earth
  - Most promising near-term uses are for life support systems and propellants

- **The Moon has many natural resources**
  - Sunlight
  - Solar Wind
  - High Ca and Al plagioclase
  - High Fe and Ti basalt
  - Pyroclastic deposits
  - Polar Volatiles

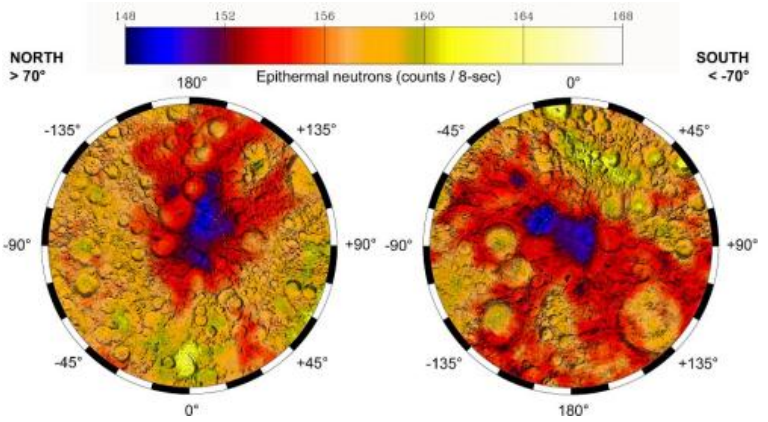
- **Polar water ice, a possible 'game changer'**
  - Water production possibly less complex
  - Water storage less complex than cryogenics
  - Measurements indicate a large abundance
  - Other volatiles and ices may also be beneficial
    - H_2S, NH_3, SO_2, C_2H_4, CO_2, CH_3,OH, CH_4, OH



Lunar Polar Water Ice

Neutron Spectroscopy

- Neutron spectrometers flown on both Lunar Prospector and Lunar Reconnaissance Orbiter (LRO)
- Feldman et al., *Science* **281**, 1496 (1998); Mitrofanov et al., *Science* **330**, 483 (2010)
- Detected “excess” hydrogen (~2-3x global average) associated with large polar regions, particularly permanently shadowed regions
- Enhanced hydrogen over poles consistent with ~1-2% water ice or increased amount of retained solar wind
- State, or nature, of hydrogen not determined

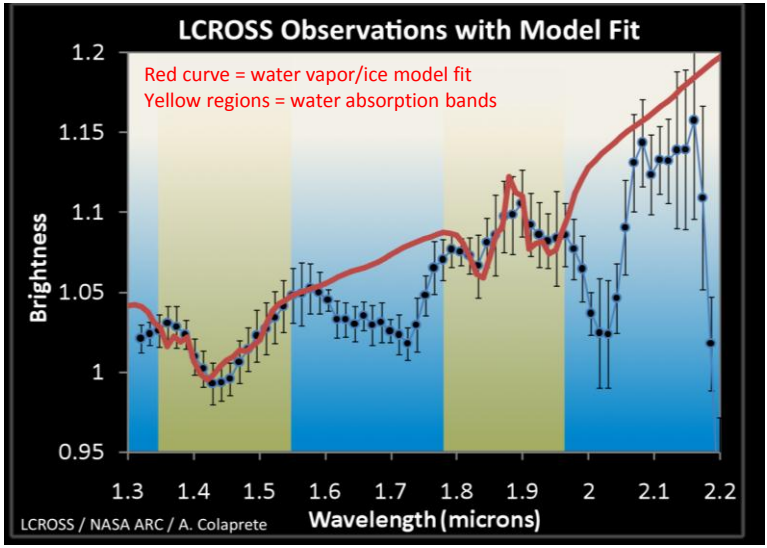


Radar Experiments

- Clementine bi-static radar experiment; Chrandrayaan-1 Mini-SAR instrument; LRO Mini-RF instrument
- Spudis et al., *Sol. Sys. Res.* **32**, 17 (1998); Spudis et al., *J. Geophys. Res. Planets* **118**, 1 (2013)
- Circular polarization ratio (CPR) and coherent backscatter opposition effect (CBOE) from polar locations on the Moon suggest the presence of water ice

Lunar Crater Observation and Sensing Satellite (LCROSS)

- Impacted permanently shadowed floor of Cabeus crater near south pole
- Provided direct evidence of water vapor in ejecta plume
- Colaprete et al., *Science* **330**, 463 (2010)
- Average concentration of water ice in the regolith is estimated to be 5.6 ± 2.9% by mass
- Results suggest there is spatial heterogeneity of water ice at scales <10km



Polar Volatiles Coordination

- **Formed small team of ISECG participating agency representatives to develop a proposal for an international strategy to coordinate and assess lunar polar volatiles**

  CSA (Vicky Hipkin, Martin Picard)
  DLR (Norbert Henn, Oliver Angerer)
  ESA (Bernhard Hufenbach, James Carpenter)
  JAXA (Naoki Sato, Takeshi Hoshino)
  NASA (Nantel Suzuki, John Gruener)
  Roscosmos (Georgy Karabadzhak)

- **Goal: Establish an internationally-coordinated effort to address exploration and scientific knowledge gaps related to lunar water ice and other polar volatiles**

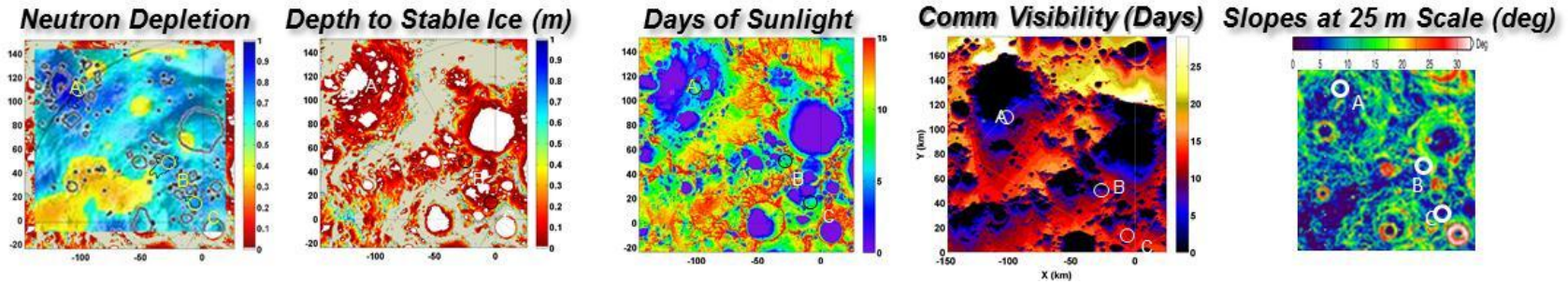
- **Objectives**
  - Seek answers regarding the quantity, distribution and form of volatiles
  - Identify initial, affordable small-scale ISRU demonstrations and experiments to understand whether water ice could be economically extracted and utilized
  - Pursue science questions regarding the delivery, transport, accretion, and composition of lunar polar volatiles
  - Stimulate collaboration and coordination of relevant capability development and lunar mission planning
  - Identify the means of exploiting lunar polar volatiles as a resource for further scientific exploration and discovery

Strategic Issues with Polar Volatile Exploration

- **What do we want to know and how do we find out?**
  - What are the key knowledge gaps, both scientific and resource related, to be answered?
  - What hypotheses can be developed and tested at the lunar surface to answer these questions?
  - What measurements could be applied to help formulate or test these hypotheses and support landing site selection for surface missions?
    - From orbit
    - From the lunar surface
    - Mobility
    - Permanently shadowed region (PSR) access
    - Drilling
    - Sample analysis
    - Sample return
  - What other science questions can be addressed at the poles and how does this affect landing site priority?
  - Which are the most significant regions of interest for making measurements?

An Example: Common Lunar Regions of Interest

Global Data Provided by Orbital Instruments



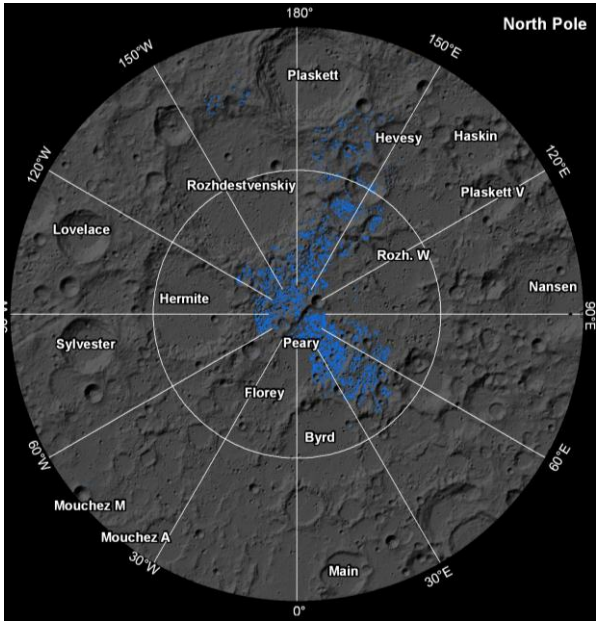
- **Core Element to Coordinated Lunar Polar Volatiles Coordination**
  - Build consensus among broad community for common "Regions" on the lunar surface to be collectively explored by a variety of sequential, coordinated missions. "Regions" are larger than a lunar site for a single mission, perhaps including distances up to a few 10s of km
- **Desirable Attributes**
  - Access to surface and/or subsurface enhanced hydrogen deposits as measured from lunar orbit
  - Access to sites of high solar illumination
  - Access to permanently shadowed regions (PSRs) and/or partially sunlit areas
  - Reasonable terrain for multiple landing locations
  - Reasonable terrain for conducting traverses (i.e., low slope angles, low boulder count)
  - Direct view of Earth for communications
- **Possible Coordination Activities**
  - Prospecting and mapping of volatile deposits over a larger area in same region
  - Communication/navigation relay between multiple landed systems (may require line-of-sight)
  - Missions of opportunity for individual science instruments/sensors, or excavation systems

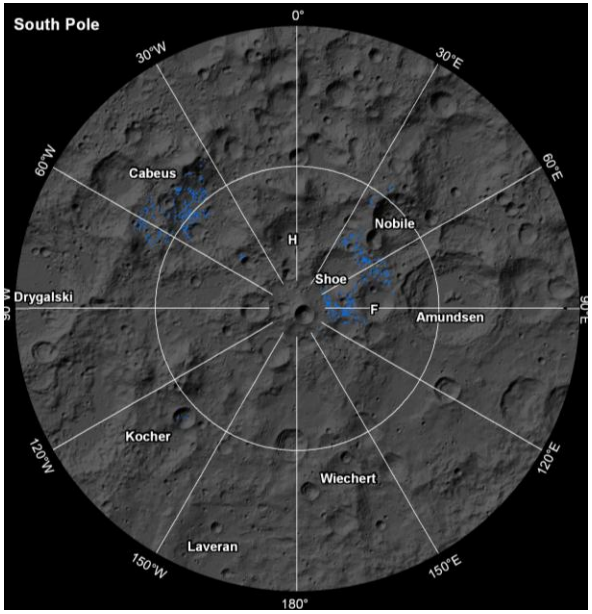
LEAG Polar Volatiles Specific Action Team

- **NASA chartered the Lunar Exploration Analysis Group (LEAG)**
  - To assess if additional orbital remote sensing measurements are required to support landed missions
  - To conduct an assessment of the current state of knowledge, select and prioritize regions of interest with the potential of accessible volatiles

- **Findings**
  - There are sufficient data to support near-term landing site selections
  - Small near-term robotic missions can provide critical data to resolve important unknowns regarding polar volatile science and resource utilization
  - At both poles there are regions that are generally suitable for common landing regions
    - Peary vicinity (north pole)
    - Cabeus vicinity (south pole)
    - Shoemaker/Nobile vicinities (south pole)

- **http://www.lpi.usra.edu/leag/reports.shtml**





Strategic Issues with Polar Volatiles Exploration

ISECG

How can we lower the cost?

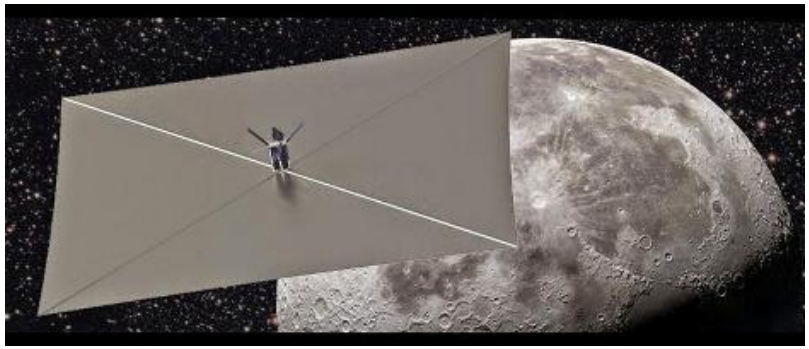
- Are there low cost innovative approaches that could be considered? (e.g. impactors, penetrators, cubesats, S/C end of life uses)
- How can the costs of access to the lunar surface be reduced?
  - Ride share
  - Procuring key mission elements as commercial services
  - Using smallsat and nanosat technologies
  - Utilizing common infrastructure/mission elements (e.g., power generation, thermal protection, communication relays, navigation beacons)
  - Utilizing existing assets from previous missions

How can we coordinate?

- Which is a better coordination approach to making measurements with several surface missions
  - All within a common region of interest?
  - Each to a different region of interest?
- How can common measurements and calibration standards etc. be utilised between missions to allow comparison of results and add value to individual data sets?
- What standards can be applied and what benefits would they bring?
  - Interfaces (e.g. mechanical, electrical, communication)
  - Propellant
  - Interchangeability of vehicle payload complements to maximize interoperability

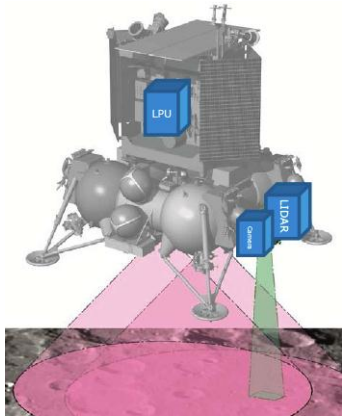
Current Activities - NASA

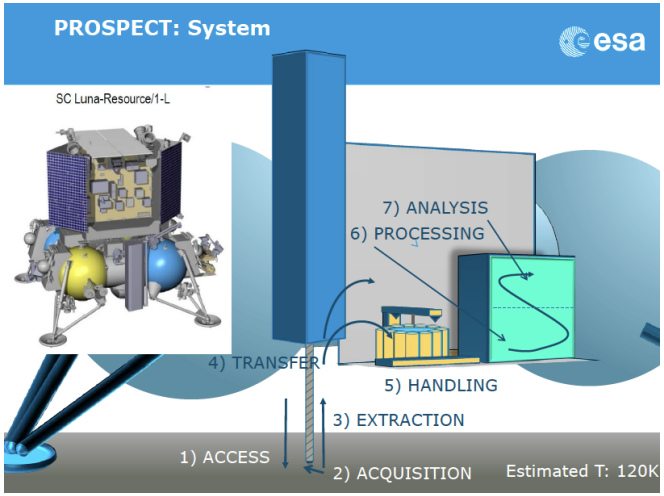
- **Resource Prospector**
  - Advanced Exploration Systems (AES) project
  - Instrumented rover
    - Neutron and Near-IR Spectrometers
    - Gas Chromatograph/Mass Spectrometer
- **Lunar Cubesat Orbital Missions**
  - Launched on SLS Exploration Mission-1
  - Lunar Flashlight (JPL, MSFC)
    - 4-band point spectrometer
  - Lunar IceCube (Morehead State University)
    - IR Spectrometer
- **Lunar CATALYST**
  - Astrobotic Technology
  - Masten Space Systems
  - Moon Express
- **Lunar Exploration Analysis Group (LEAG)**
  - Polar volatiles strategic action team

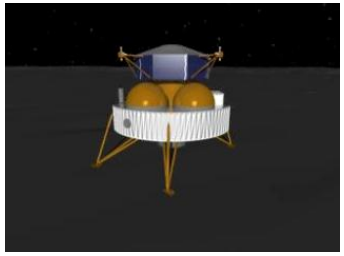


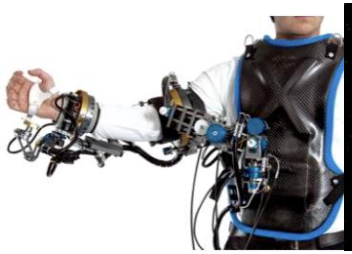
Current Activities – ESA

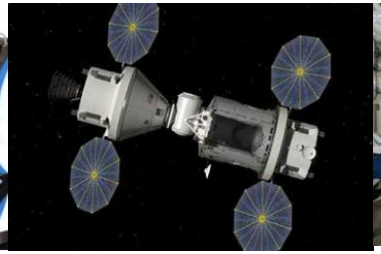
- **ESA Collaborations with RSA Luna 27**
  - PILOT
    - Precision landing
    - Hazard avoidance
  - PROSPECT
    - Drilling down to 2 meters
    - Evolved Gas Analyser
- **ESA Human-Enhanced Robotic Architecture and Capability for Lunar Exploration and Science (HERACLES)**
  - Develop exploration technologies and capabilities
  - Perform science to enable human exploration
  - Stimulate economic expansion





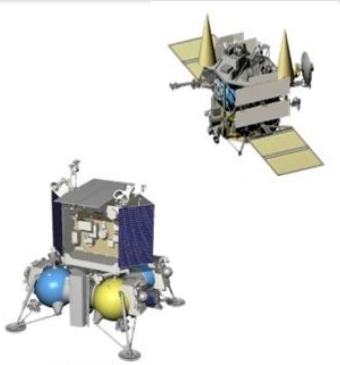


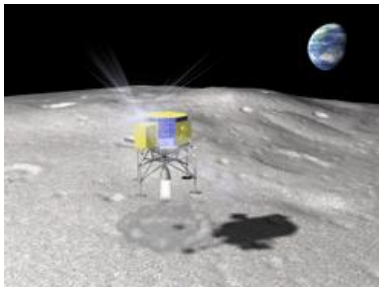


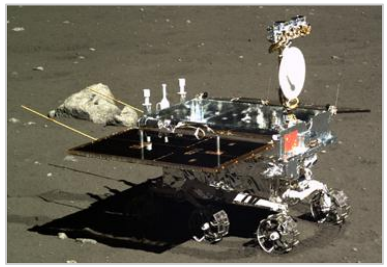


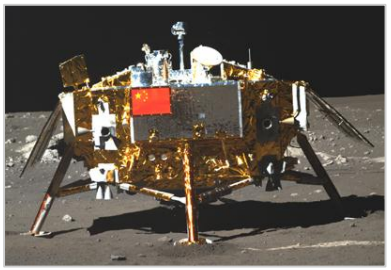
Current Activities – Other Agencies

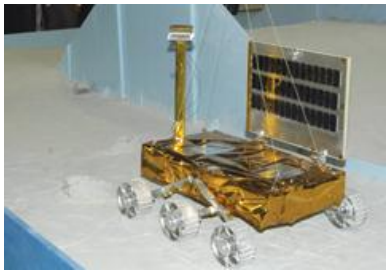
- **Russian Space Agency (RSA)**
  - Luna 25 (Luna-Glob) Polar Lander
  - Luna 26 (Luna-Resurs O) Orbiter
  - Luna 27 (Luna-Resurs 1)Polar Lander
- **Japan Aerospace Exploration Agency (JAXA)**
  - SELENE-2 polar lander study
  - Collaborating with NASA Resource Prospector
  - Smart Lander for Investigation Moon (SLIM)
- **China National Space Administration (CNSA)**
  - Chang'e 4 collaborations possible
  - Polar landing (or farside) possible
- **Canadian Space Agency (CSA)**
  - Lunar rovers (in development)
- **Korea Aerospace Research Institute (KARI)**
  - Lunar orbiter, lander, rover (in formulation)
- **Indian Space Research Organization (ISRO)**
  - Chandrayaan-2 (orbiter, lander, rover)











2015-2025 An Exciting Decade for Lunar Exploration

- **The International Space Exploration Coordination Group (ISECG) is working to exchange information regarding interests, objectives, and plans in space exploration with the goal of strengthening both individual exploration programs as well as the collective effort**
  - International Space Station (ISS)Moon and cis-lunar space
  - Near-Earth asteroids Mars

- **Space agencies agree that human space exploration will be most successful as an international endeavor, given the challenges of these missions**

- **Lunar resources, including polar volatiles, may be an important part of a sustainable, affordable long-term human presence beyond low-Earth orbit, but there are many questions as to their use that need to be answered first**

- **Soon, more on lunar polar volatiles coordination at http://www.globalspaceexploration.org**

- **For more information, contact us at**
  - John Gruener, john.e.greuner@nasa.gov
  - Nantel Suzuki, nantel.h.suzuki@nasa.gov
  - James Carpenter, james.carpenter@esa.int

The Lunar Polar Regions Today